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U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

10.2.3 TURBINE ~~DISK~~ROTOR[1] INTEGRITY

REVIEW RESPONSIBILITIES

Primary - ~~Materials Engineering Branch (MTEB)~~ Civil Engineering and Geosciences Branch (ECGB)[2]

Secondary - ~~None~~Materials and Chemical Engineering Branch (EMCB)[3]

I. AREAS OF REVIEW

General Design Criterion 4 (GDC 4)[4] requires that structures, systems, and components important to safety shall be appropriately protected against environmental and dynamic effects, including the effects of missiles, that may result from equipment failure. Because turbine ~~disk~~rotors have large masses and rotate at relatively high speeds during normal reactor operation, failure of a ~~disk~~rotor may result in the generation of high energy missiles and cause excessive vibration of the turbine rotor assembly. Measures taken by the applicant to ~~assure~~ ensure[5] turbine ~~disk~~rotor integrity and reduce the probability of turbine ~~disk~~rotor failure satisfy the relevant requirements of ~~General Design Criterion 4~~ GDC 4.[6]

The purpose of this section of the Standard Review Plan (SRP)[7] is to review and evaluate the information submitted by the applicant to ~~assure~~ ensure turbine ~~disk~~rotor integrity and a low probability of turbine ~~disk~~rotor failure with the generation of missiles.

The following areas of the applicant's safety analysis report (SAR) relating to turbine ~~disk~~rotor integrity are reviewed:

1. Materials Selection

   The low-pressure turbine rotor assembly ~~usually~~ may consist~~s~~ of a rotor shaft with shrunk-on disks or a one-piece rotor using either an integral forging or welded design.[8]

Low-pressure ~~disk~~rotor stresses are due to thermal gradients, the interference fit, and centrifugal forces. These stresses are relatively high. The low-pressure turbine operates at lower temperatures than the high-pressure turbine. Thus, it is particularly important that low-pressure ~~disk~~rotors be made of a tough material. The use of suitable design, materials, fabrication techniques, coating processes, nondestructive examinations during the fabrication process,[9] and inservice inspection can greatly reduce the probability of a turbine ~~disk~~rotor failure.

The materials properties, including descriptions of the procedures to minimize flaws and improve fracture toughness, are reviewed to establish that sufficient information is provided to permit an evaluation of the adequacy of the low-pressure ~~disk~~rotor materials.

Included in this information are:

a. A discussion of the ductile-brittle transition temperatures (FATT or NDT) of the materials and the tests and standards used to determine them.

b. The Charpy V-notch test program used to establish minimum upper-shelf energies of the ~~disk~~rotor materials.

c. The fracture toughness test program used to establish minimum upper-shelf toughness of the ~~disk~~rotor materials.

2. Fracture Toughness

The fracture toughness of the materials and the materials tests or correlations of Charpy and tensile data to toughness properties are reviewed to establish that the turbine ~~disk~~rotor materials exhibit adequate fracture toughness at normal operating temperature and during startup.

3. Preservice Inspection

The preservice inspection program information is reviewed to verify that the ~~disk~~rotor forgings are first machined with minimum excess stock prior to heat treatment; that visual and surface inspections are performed on all finished machined surfaces; ~~and~~ that a 100% volumetric (ultrasonic) examination is performed; that before welding and/or brazing, all surfaces prepared for welding will be surface examined; that after welding and/or brazing, all surfaces exposed to steam will be surface examined, giving particular attention to stress risers and welds; and that welds will be ultrasonically examined in the radial and radial-tangential sound beam directions.[10]

4. Turbine ~~Disk~~Rotor Design

The low-pressure turbine rotor design information, including allowable stresses, temperature distributions, and design overspeed considerations, is reviewed.

5. Inservice Inspection

Descriptions of the baseline and inservice phases of the inservice inspection program, including types of inspections, areas to be inspected, frequencies of inspection, and acceptance criteria, are reviewed.

II. ACCEPTANCE CRITERIA

~~MTEB~~ The NRC[11] acceptance requirement is based on meeting the relevant requirements of ~~General Design Criterion 4~~ GDC 4, "Environmental and ~~Missile~~ Dynamic Effects[12] Design Bases," as it relates to structures, systems, and components important to safety being appropriately protected against environmental and dynamic effects, including the effects of missiles, that may result from equipment failure. The specific criteria necessary to meet the relevant requirements of GDC 4 to reduce the probability of failure of the turbine ~~disk~~rotor are as follows:

1. Materials Selection

The turbine ~~disk~~ forged or welded rotor[13] should be made from a material and by a process that tends to minimize flaw occurrence and maximize fracture toughness properties, such as a NiCrMoV alloy processed by vacuum melting or vacuum degassing. The material should be examined and tested to meet the following criteria:

a. Chemical analysis should be made for each forging. Elements that have a deleterious effect on toughness, such as sulfur and phosphorus, should be controlled to low levels.

b. The fracture appearance transition temperature (50% FATT) as obtained from Charpy tests performed in accordance with specification ASTM A-370[14] should be no higher than -18°C (O°F)[15] for low-pressure turbine ~~disk~~rotors. Nil-ductility transition (NDT) temperature obtained in accordance with specification ASTM E-208[16] may be used in lieu of FATT. NDT temperatures should be no higher than -35°C (-30°F).[17]

c. The Charpy V-notch (C_v) energy at the minimum operating temperature of each low-pressure ~~disk~~rotor in the tangential direction should be at least 8.3 kg-m (60 ft-lbs).[18] A minimum of three C_v specimens should be tested in accordance with specification ASTM A-370.

2. Fracture Toughness

The low-pressure turbine ~~disk~~ forged or welded rotor[19] fracture toughness properties are acceptable if in compliance with the following criteria:

The ratio of the fracture toughness (K_{Ic}) of the ~~disk~~rotor material to the maximum tan ential stress at speeds from normal to design overspeed should be at least ~~two~~ 10 √mm (2 √in),[20] at minimum operating temperature. Bore stress calculations should include components due to centrifugal loads, interference fit, and thermal gradients. Sufficient warmup time should be specified in the turbine operating instructions to ~~assure~~

ensure that toughness will be adequate to prevent brittle fracture during startup. Fracture toughness properties can be obtained by any of the following methods:

a. Testing of the actual material of the turbine ~~disk~~rotor to establish the K_{Ic} value at normal operating temperature.

b. Testing of the actual material of the turbine ~~disk~~rotor with an instrumented Charpy machine and a fatigue precracked specimen to establish the K_{Ic} (dynamic) value at normal operating temperature. If this method is used, K_{Ic} (dynamic) shall be used in lieu of K_{Ic} (static) in meeting the toughness criteria above.

c. Estimating of K_{Ic} values at various temperatures from conventional Charpy and tensile data on the ~~disk~~rotor material using methods presented by J. A. Begley and W. A. Logsdon in Westinghouse Scientific Paper 71-1E7-MSLRF-P1 ~~(Ref. 5)~~.[21] This method of obtaining K_{Ic} should be used only on materials which exhibit a well-defined Charpy energy and fracture appearance transition curve and are strain-rate insensitive. The test data and the calculated toughness curve should be submitted to the staff for review.

d. Estimating "lower bound" values of K_{Ic} at various temperatures using the equivalent energy concept of F. J. Witt and T. R. Mager, ORNL-TM-3894 ~~(Ref. 6)~~.[22] Load-displacement data from the compact tension specimens and the calculated toughness data should be submitted to the staff for review.

3. <u>Preservice Inspection</u>

The applicant's preservice inspection program is acceptable if in compliance with the following criteria:

a. ~~Disk forgings~~Forged or welded rotors[23] should be rough machined prior to heat treatment.

b. Each finished ~~disk~~forged or welded rotor[24] should be subjected to 100% volumetric (ultrasonic), surface, and visual examinations using procedures and acceptance criteria equivalent to those specified for Class 1 components in the ASME Boiler and Pressure Vessel Code, Sections III and V. Before welding and/or brazing, all surfaces prepared for welding and/or brazing should be surface examined. After welding and/or brazing, all surfaces exposed to steam should be surface examined, giving particular attention to stress risers and welds. Welds should be ultrasonically examined in the radial and radial-tangential sound beam directions.[25]

c. Finish machined bores, keyways, and drilled holes should be subjected to magnetic particle or liquid penetrant examination. No flaw indications in keyway or hole regions are allowable.

d. Each turbine rotor assembly should be spin tested at 5% above[26] the maximum speed anticipated during a turbine trip following loss of full load.

4. <u>Turbine ~~Disk~~Rotor Design</u>

The applicant's design is acceptable if in compliance with the following:

The turbine assembly should be designed to withstand normal conditions, anticipated transients, and accidents resulting in a turbine trip without loss of structural integrity. The design of the turbine assembly should meet the following criteria:

a. The design overspeed of the turbine should be 5% above the highest anticipated speed resulting from a loss of load. The basis for the assumed design overspeed should be submitted to the staff for review.

b. The combined stresses of low-pressure turbine ~~disk~~rotor at design overspeed due to centrifugal forces, interference fit, and thermal gradients should not exceed 0.75 of the minimum specified yield strength of the material, or 0.75 of the measured yield strength in the weak direction of the materials if appropriate tensile tests have been performed on the actual ~~disk~~rotor material.

c. The turbine shaft bearings should be able to withstand any combination of the normal operating loads, anticipated transients, and accidents resulting in turbine trip.

d. The natural critical frequencies of the turbine shaft assemblies existing between zero speed and 20% overspeed should be controlled in the design and operation so as to cause no distress to the unit during operation.

e. The turbine ~~disk~~rotor design should facilitate inservice inspection of all high stress regions, including bores and keyways~~, without the need for removing the disks from the shaft~~.[27]

5. <u>Inservice Inspection</u>

The applicant's inservice inspection program is acceptable if in compliance with the following criteria:

The inservice inspection program for the steam turbine assembly should provide assurance that ~~disk~~rotor flaws that might lead to brittle failure of a ~~disk~~rotor at speeds up to design speed will be detected. The inservice inspection and maintenance program for the turbine assembly should ~~include the following:~~comply with the manufacturers recommendations.

~~Disassembly of the turbine at approximately 10-year intervals,~~Inservice inspection and maintenance activities may be performed during plant shutdown coinciding with the inservice inspection schedule as required by ASME Boiler and Pressure Vessel Code, Section XI, and should include[28] complete inspection of all normally inaccessible parts, such as couplings, coupling bolts, turbine shafts, low-pressure turbine blades, low-pressure ~~disk~~rotors, and high-pressure rotors. This inspection should consist of visual, surface, and volumetric examinations, as required.

Technical Rationale[29]

The technical rationale for application of these acceptance criteria to reviewing turbine rotor integrity is discussed in the following paragraphs:[30]

Compliance with GDC 4 requires in part that structures, systems, and components important to safety be designed to accommodate the effects of, and be compatible with, environmental conditions associated with normal operations, maintenance, testing, and postulated accidents, including loss-of-coolant accidents. These structures, systems, and components shall be appropriately protected against dynamic effects, including missiles caused by equipment failures.

GDC 4 applies to this SRP section because the turbine is a potential source of high-energy missiles that could compromise the function of plant components designated as important to safety. Protection from these missiles is provided by placing specific requirements on turbines relative to materials, fabrication, inspections during fabrication, and inservice inspections, thus ensuring that failure of a turbine will be highly unlikely.

Meeting the requirements of GDC 4 provides assurance that the turbine will not be a source of missiles that could damage systems, structures, and components, thereby decreasing the potential for release of fission products to the environment that could lead to offsite doses in excess of reference values cited in 10 CFR Part 100.[31]

III. REVIEW PROCEDURES

For each area of review, the following review procedures are followed:

1. Materials Selection

   The materials properties and the procedures to minimize flaws and improve fracture toughness, as described by the applicant, are reviewed and compared with the requirements of subsection II.l of this SRP section. If a new material not used in prior licensed cases is utilized, the applicant's materials selection is reviewed and evaluated to establish its acceptability. Such an evaluation is based on the acceptance criteria of subsection II of this SRP section.

2. Fracture Toughness

   The fracture toughness properties of the low-pressure turbine disk or forged or welded rotor[32] material, including specimen test data, where applicable, are reviewed and compared with the requirements of subsection II.2 of this SRP section. The applicant is permitted any of three alternates for deriving the fracture toughness of the ~~disk~~rotor materials.

3. Preservice Inspection

The preservice inspection program, including finish machining, ultrasonic inspection, surface inspection, visual inspection, and spin testing, is reviewed and compared with the requirements of subsection II.3 of this SRP section. The extent to which the ultrasonic inspections and the acceptance criteria in the SAR agree with ASME Boiler and Pressure Vessel Code, Section III, NB-2530 for plate materials or NB-2540 for forgings, is reviewed.

4. Turbine ~~Disk~~Rotor Design

The design and stress analysis procedures used for the low-pressure turbine disks or forged or welded rotors[33] are reviewed including the following areas:

a. Load combinations at normal operating speed and allowable stresses.

b. Design overspeed and basis for selection of design overspeed.

c. Load combinations at design overspeed and allowable stresses.

The SAR data are compared and evaluated against subsection II.4 of this SRP section.

5. Inservice Inspection

The inservice inspection and maintenance[34] program described by the applicant, including areas to be inspected, methods of inspection, frequency of inspection, and acceptance criteria, is reviewed and compared with the requirements of subsection II.5 of this SRP section.

For standard design certification reviews under 10 CFR Part 52, the procedures above should be followed, as modified by the procedures in SRP Section 14.3 (proposed), to verify that the design set forth in the standard safety analysis report, including inspections, tests, analysis, and acceptance criteria (ITAAC), site interface requirements and combined license action items, meet the acceptance criteria given in subsection II. SRP Section 14.3 (proposed) contains procedures for the review of certified design material (CDM) for the standard design, including the site parameters, interface criteria, and ITAAC.[35]

IV. EVALUATION FINDINGS

The staff concludes that the integrity of the low-pressure turbine ~~disk~~forged or welded rotor[36] is acceptable and meets the relevant requirements of General Design Criterion 4 of 10 CFR Part 50. This conclusion is based upon the following:

The applicant has met the requirements of General Design Criterion 4 of 10 CFR Part 50 with respect to the use of materials with acceptable fracture toughness and elevated temperature properties, adequate design, and the requirements for preservice and inservice inspections. The applicant has described ~~his~~ a[37] program for ~~assuring~~ ensuring the integrity of low-pressure turbine ~~disk~~rotors by the use of suitable materials of adequate fracture toughness, conservative design practices, and preservice and inservice inspections. The staff concurs that these provisions provide reasonable assurance that the probability of failure with missile generation is low during normal operation, including transients up to design overspeed.

For design certification reviews, the findings will also summarize, to the extent that the review is not discussed in other safety evaluation report sections, the staff's evaluation of inspections, tests, analyses, and acceptance criteria (ITAAC), including design acceptance criteria (DAC), site interface requirements, and combined license action items that are relevant to this SRP section.[38]

V. IMPLEMENTATION

The following is intended to provide guidance to applicants and licensees regarding the NRC staff's plan for using this SRP section.

This SRP section will be used by the staff when performing safety evaluations of license applications submitted by applicants pursuant to 10 CFR 50 or 10 CFR 52.[39] Except in those cases in which the applicant proposes an acceptable alternative method for complying with specific portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of conformance with the Commission regulations.

The provisions of this SRP section apply to reviews of applications docketed six months or more after the date of issuance of this SRP section.[40]

VI. REFERENCES

1. 10 CFR Part 50, Appendix A, General Design Criterion 4, "Environmental and ~~Missile~~ Dynamic Effects[41] Design Bases."

2. ASME Boiler and Pressure Vessel Code, Sections III, V, and XI, American Society of Mechanical Engineers.

3. ASTM E-208-1969[42], "Standard Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels," Annual Book of ASTM Standards, Part 31, American Society for Testing Materials.

4. ASTM A-370-1972[43], "Standard Methods and Definitions for Mechanical Testing of Steel Products," Annual Book of ASTM Standards, Parts 1, 2, 3, 4, or 31, American Society for Testing Materials.

5. J. A. Begley and W. A. Logsdon, Scientific Paper 71-1E7-MSLRF-P1, Westinghouse Electric Corp., July 26, 1971.

6. F. J. Witt and T. R. Mager, ORNL-TM-3894, Oak Ridge National Laboratory (1972).

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Attachment A - Proposed Changes in Order of Occurrence

Item numbers in the following table correspond to superscript numbers in the redline/strikeout copy of the draft SRP section.

Item	Source	Description
1.	PRB Comment Resolution	Revised the title and made global changes to the text of SRP Section 10.2.3 to replace "disk" with "rotor" in accordance with PRB comments.
2.	Current PRB name and abbreviation, PRB Comment Resolution	Identified the Civil Engineering and Geosciences Branch (ECGB) as the current PRB having primary review responsibilities for SRP Section 10.2.3.
3.	Current PRB name and abbreviation, PRB Comment Resolution	Identified the Materials and Chemical Engineering Branch (EMCB) as having secondary review responsibilities for SRP Section 10.2.3.
4.	Editorial	Introduced "GDC 4" as initialism for "General Design Criterion 4."
5.	Editorial	Replaced "assure" with "ensure" (global change for this section).
6.	Editorial	Replaced "General Design Criterion 4" with "GDC 4."
7.	Editorial	Defined SRP.
8.	Integrated Impact No. 434	Added consideration of one-piece turbine rotor designs.
9.	Integrated Impact No. 434	Added consideration of testing during fabrication of the turbine rotor.
10.	Integrated Impact No. 434	Added details of testing during fabrication of the turbine rotor.
11.	PRB Comment Resolution	The PRB abbreviation was replaced with "NRC" in accordance with PRB comments.
12.	Editorial	Replaced "General Design Criterion 4" with "GDC 4," and updated title for GDC 4.
13.	Integrated Impact No. 434, PRB Comment Resolution	Deleted reference to "disk" and added reference to forged or welded turbine rotor designs.
14.	Integrated Impact No. 433	The reference to ASTM A-370 needs to be updated to ASME SA-370, 1992, provided a comparison of the two versions supports the update of the citation.
15.	SRP-UDP format item	Added SI units for temperature.
16.	Integrated Impact No. 432	The reference to ASTM E-208 needs to be updated to ASTM E-208, 1991, provided a comparison of the two versions supports the update of the citation.
17.	SRP-UDP format item	Added SI units for temperature.
18.	SRP-UDP format item	Added SI units for ft-lbs.

Item	Source	Description
19.	Integrated Impact No. 434, PRB Comment Resolution	Deleted reference to "disk" and added reference to forged or welded turbine rotor designs.
20.	SRP-UDP format item	Added SI units for ratio of the fracture toughness (KIc) to maximum tangential stress.
21.	SRP-UDP format item	Deleted unnecessary callout of Ref. 5.
22.	SRP-UDP format item	Deleted unnecessary callout of Ref. 6.
23.	Integrated Impact No. 434, PRB Comment Resolution	Deleted reference to "disk" and added reference to forged or welded turbine rotor designs.
24.	Integrated Impact No. 434, PRB Comment Resolution	Deleted reference to "disk" and added reference to forged or welded turbine rotor designs.
25.	Integrated Impact No. 434	Added details of testing during fabrication of the turbine rotor.
26.	Integrated Impact No. 434	Added 5% above design overspeed for spin testing of the fully fabricated rotor assembly.
27.	PRB Comment Resolution	Deleted text in accordance with PRB comments.
28.	PRB Comment Resolution	Revised the paragraph in accordance with PRB comments.
29.	SRP-UDP format item	Added "Technical Rationale" under ACCEPTANCE CRITERIA to describe the bases for referencing GDC 4.
30.	SRP-UDP format item	Added lead-in sentence for "Technical Rationale."
31.	SRP-UDP format item	Added technical rationale for GDC 4.
32.	Integrated Impact No. 434	Added reference to forged or welded turbine rotor designs.
33.	Integrated Impact No. 434	Added reference to forged or welded turbine rotor designs.
34.	PRB Comment Resolution	Revised the paragraph to include maintenance programs in accordance with PRB comments.
35.	SRP-UDP Guidance, Implementation of 10 CFR 52	Added standard paragraph to address application of Review Procedures in design certification reviews.
36.	Integrated Impact No. 434, PRB Comment Resolution	Deleted reference to "disk" and added reference to forged or welded turbine rotor designs.
37.	Editorial	Modified to eliminate gender-specific pronoun.

Item	Source	Description
38.	SRP-UDP Format Item, Implement 10 CFR 52 Related Changes	To address design certification reviews a new paragraph was added to the end of the Evaluation Findings. This paragraph addresses design certification specific items including ITAAC, DAC, site interface requirements, and combined license action items.
39.	SRP-UDP Guidance, Implementation of 10 CFR 52	Added standard sentence to address application of the SRP section to reviews of applications filed under 10 CFR Part 52, as well as Part 50.
40.	SRP-UDP Guidance	Added standard paragraph to indicate applicability of this section to reviews of future applications.
41.	SRP-UDP format item	Updated title of GDC 4.
42.	**Integrated Impact 1505**	Added the applicable version date to the reference for ASTM E208 in accordance with SRP-UDP guidance.
43.	**Integrated Impact 1504**	Added the applicable version date to the reference for ASTM A370 in accordance with SRP-UDP guidance.

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Attachment B - Cross Reference of Integrated Impacts

Integrated Impact No.	Issue	SRP Subsections Affected
432	Update reference to ASTM 208.	Action delayed pending detailed comparison with current version of the standard.
433	Update reference to ASTM 208.	Action delayed pending detailed comparison with current version of the standard.
434	Revise SRP Subsections to address preservice and inservice inspection of solid or welded turbine rotor designs.	Subsection I, AREAS OF REVIEW Subsection II, ACCEPTANCE CRITERIA Subsection III, REVIEW PROCEDURES Subsection IV, EVALUATION FINDINGS
1504	Update the citation of ASTM A370 to cite the 1972 version.	Subsection VI, REFERENCES
1505	Update the citation of ASTM E208 to cite the 1969 version.	Subsection VI, REFERENCES